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Taniguchi et al.

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(54) **DRILLING HEAD, METHOD OF SOIL IMPROVEMENT WORK AND APPARATUS THEREOF**

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E02D 3/12 (2006.01)

(52) **U.S. Cl.** **405/263**; 405/266; 405/269; 405/241

(58) **Field of Classification Search** 405/263, 405/266, 267, 269, 233, 240, 241, 128.75; 175/323
See application file for complete search history.

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(57) **ABSTRACT**

A method of soil improvement work drills the ground with a drilling head arranged at a lower end of a rotary shaft and sends the rotary shaft into the ground. The method mixes pressurized water with compressed air on the ground, to prepare a fluid mixture, feeds the fluid mixture through a feed path arranged along the rotary shaft into an ejector arranged on the drilling head, and ejects the fluid mixture from the ejector toward the ground to drill. An envelope defined by a front end of the drilling head has a conical shape.

5 Claims, 13 Drawing Sheets

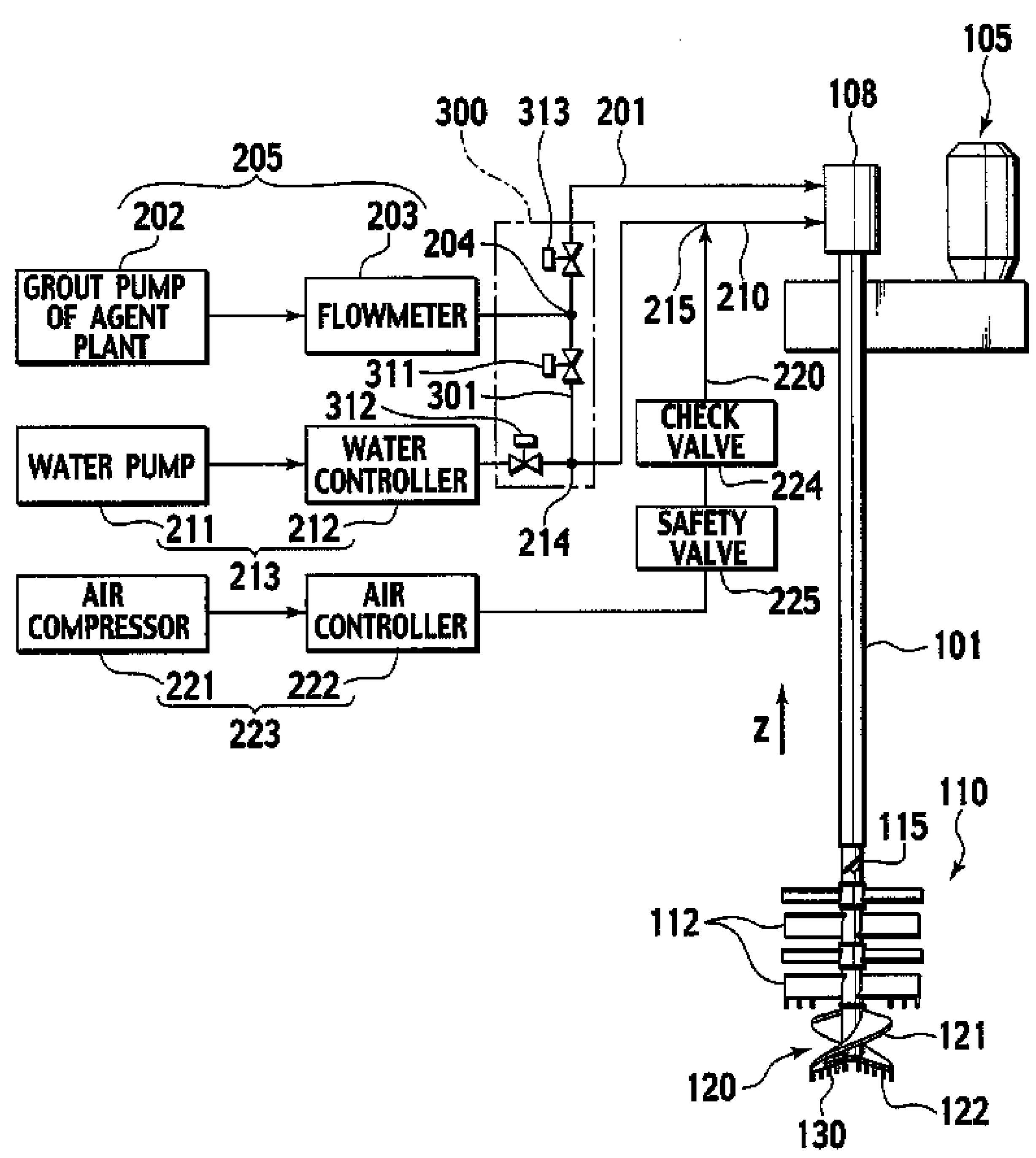


FIG. 1
PRIOR ART

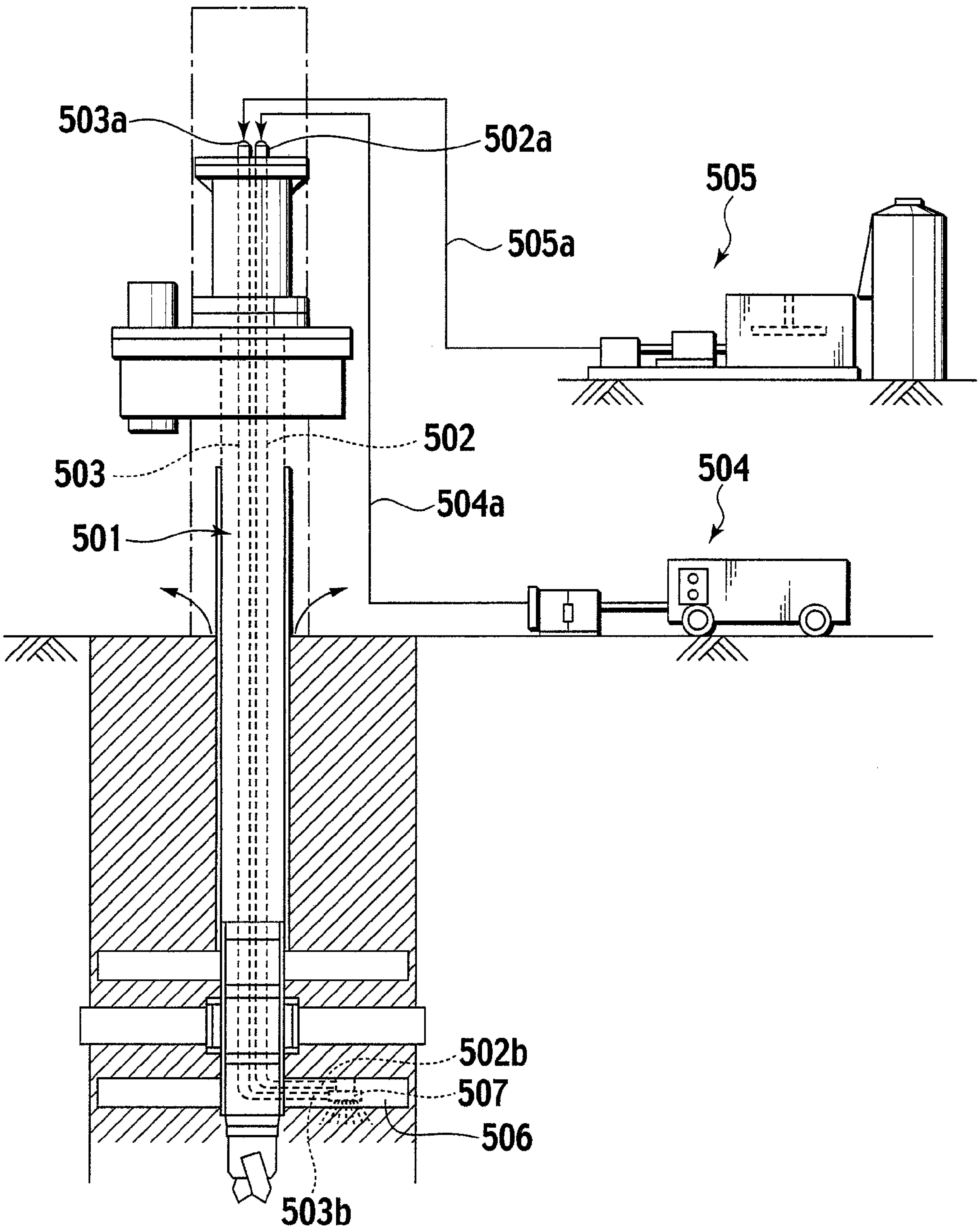


FIG. 2
PRIOR ART

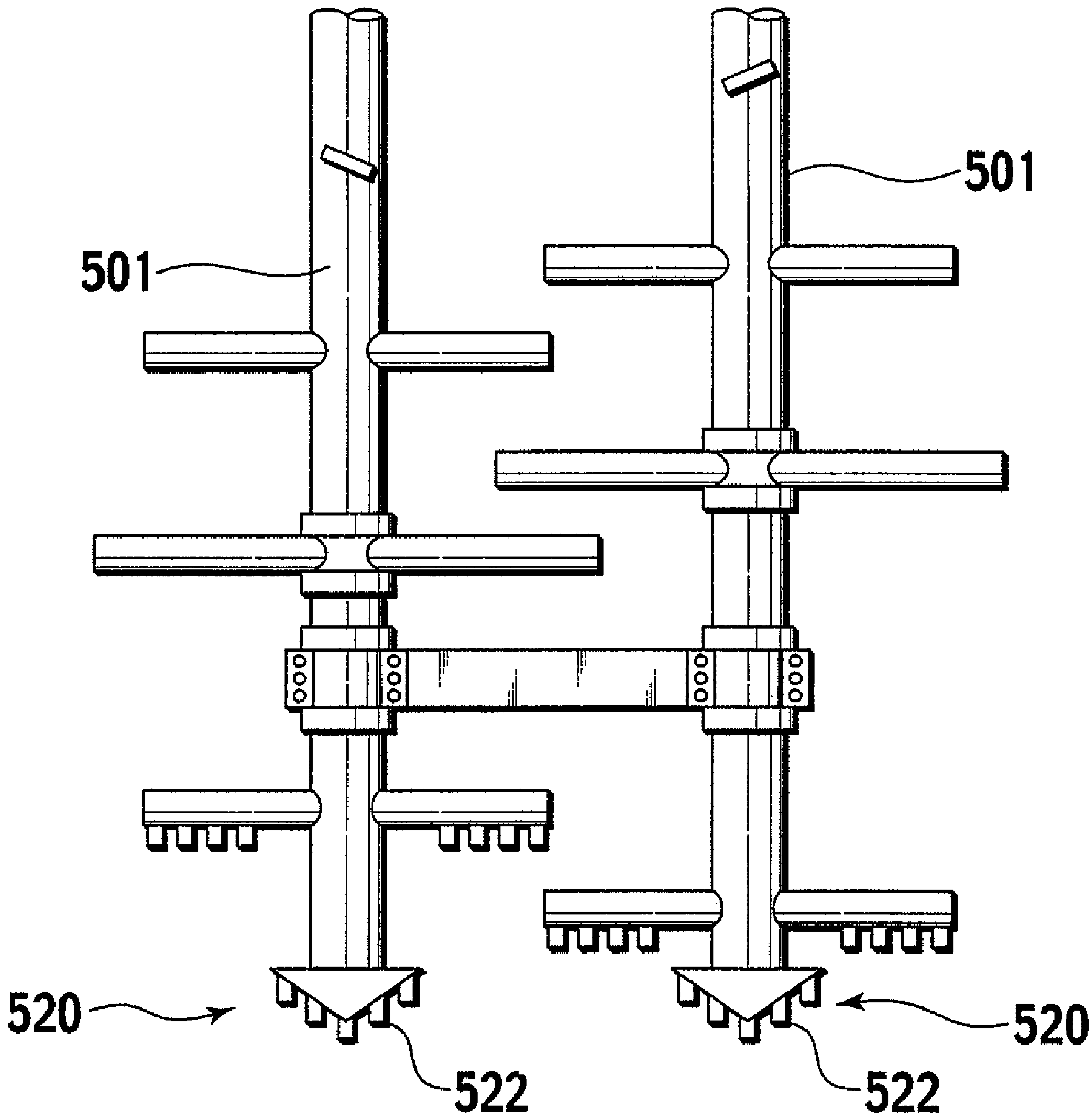


FIG. 3
PRIOR ART

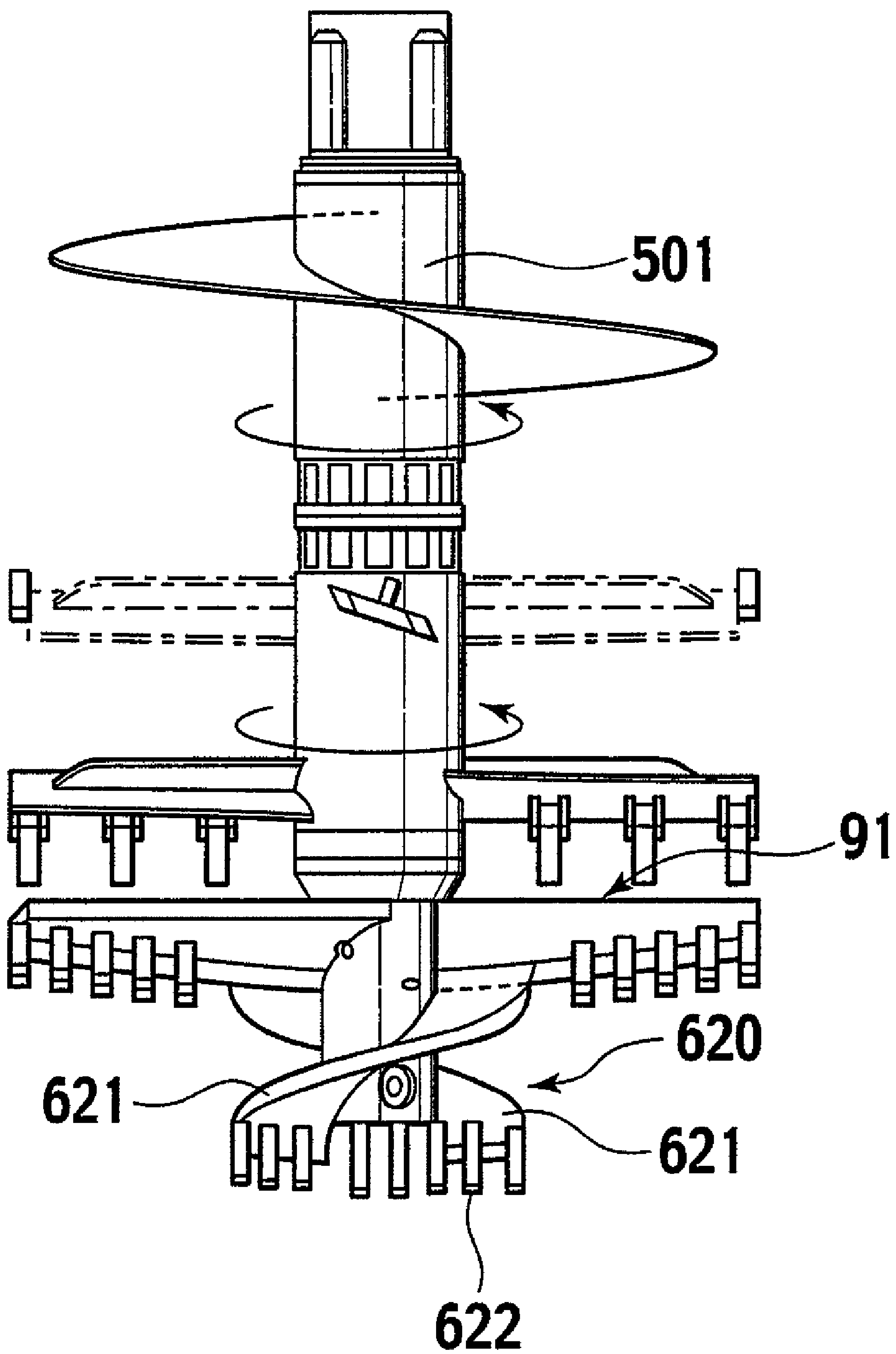


FIG. 4

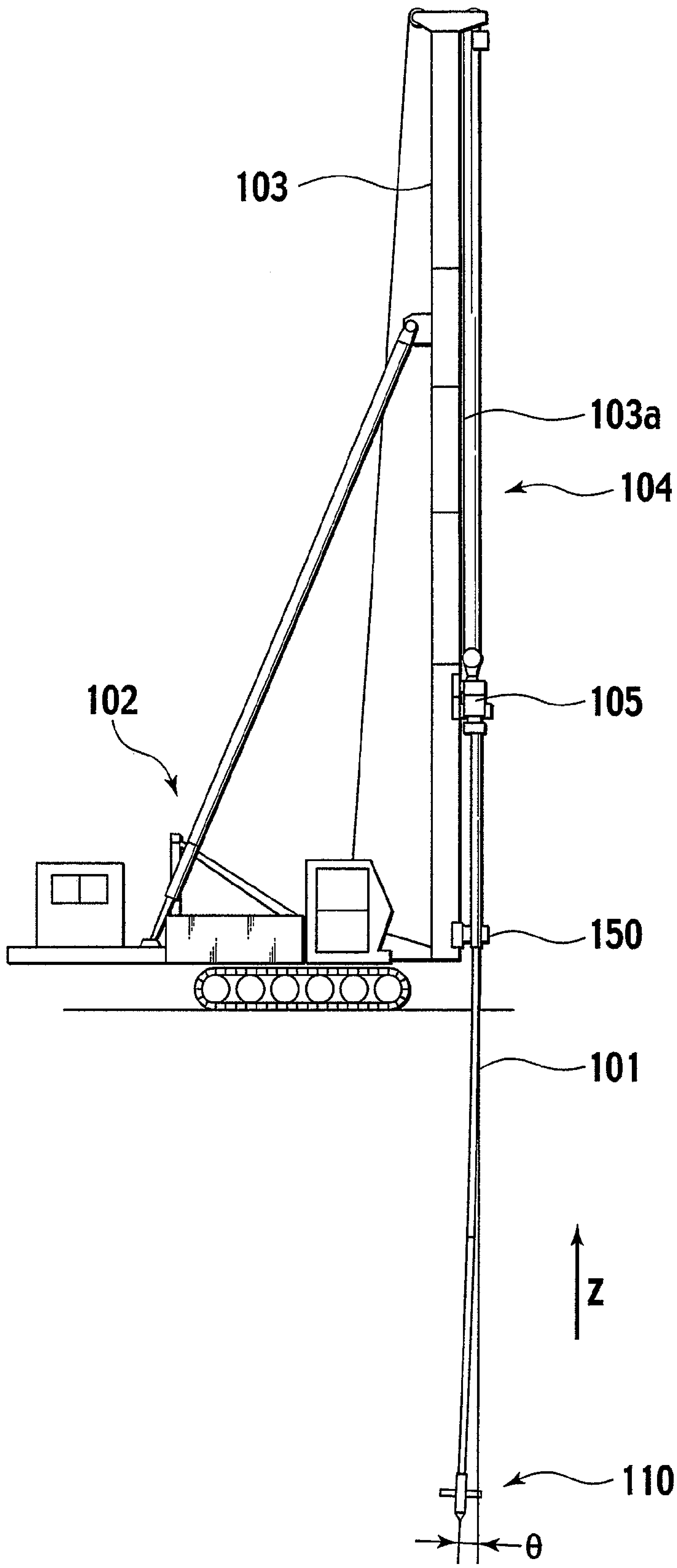


FIG. 5

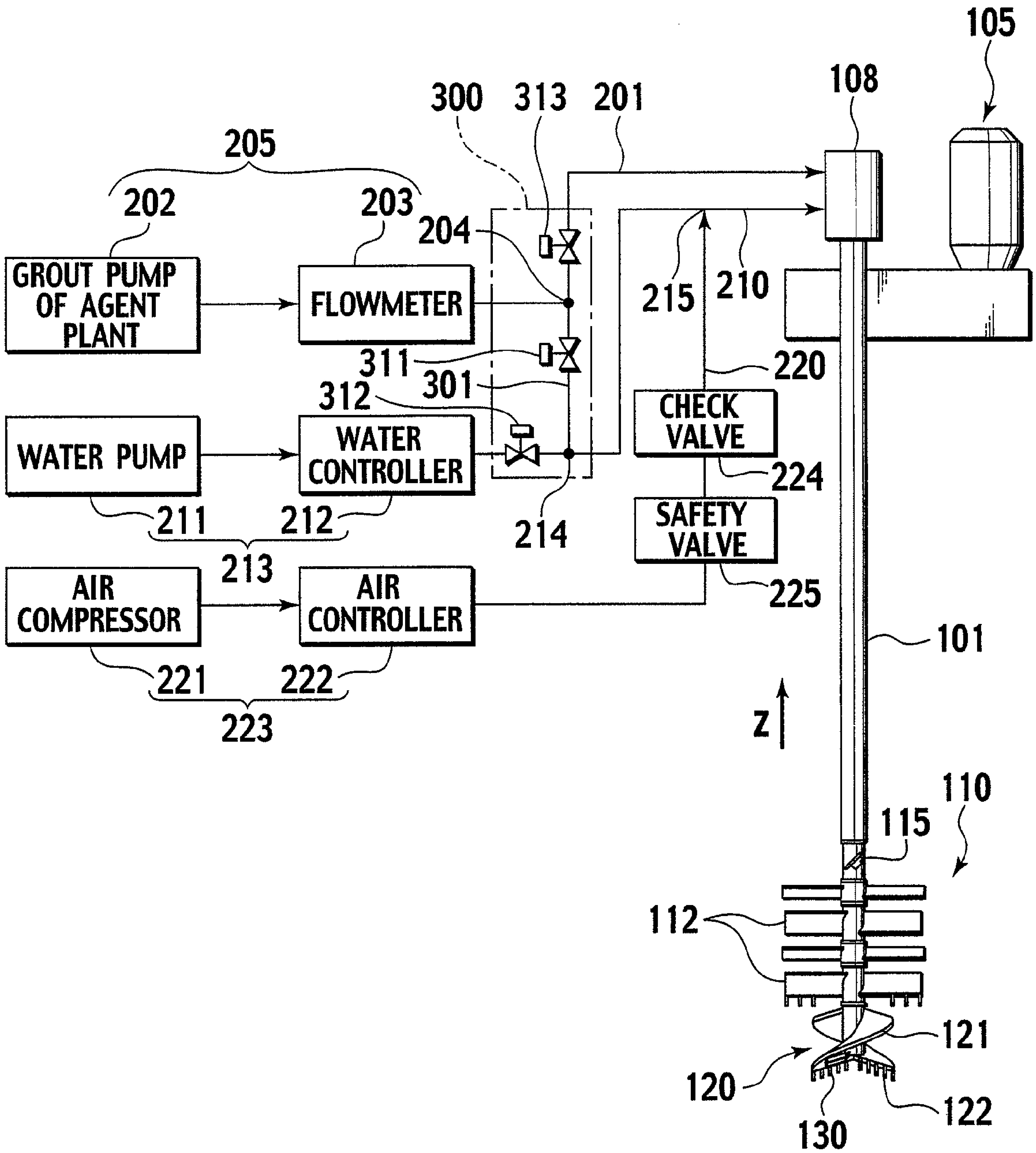

105
108
300
313
201
205
202
203
204
GROUT PUMP OF AGENT PLANT
FLOWMETER
215
210
220
311
301
312
CHECK VALVE
224
WATER PUMP
WATER CONTROLLER
214
SAFETY VALVE
225
211
212
213
AIR COMPRESSOR
AIR CONTROLLER
221
222
223
101
Z
110
115
112
121
120
122
130

FIG. 6

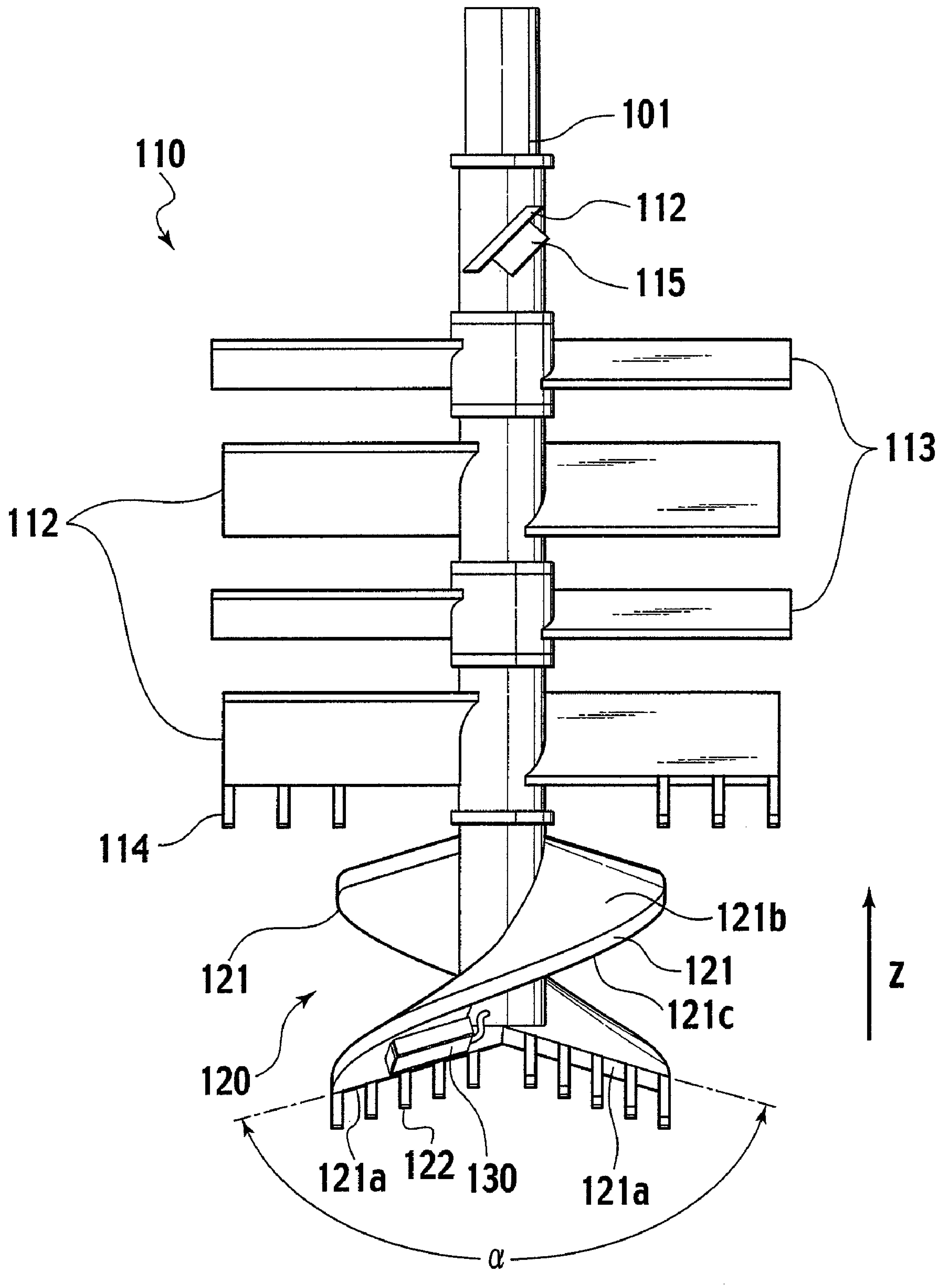

101
110
112
115
113
112
114
121b
121
121c
121
120
121a
122
130
121a
Z
α

FIG. 7

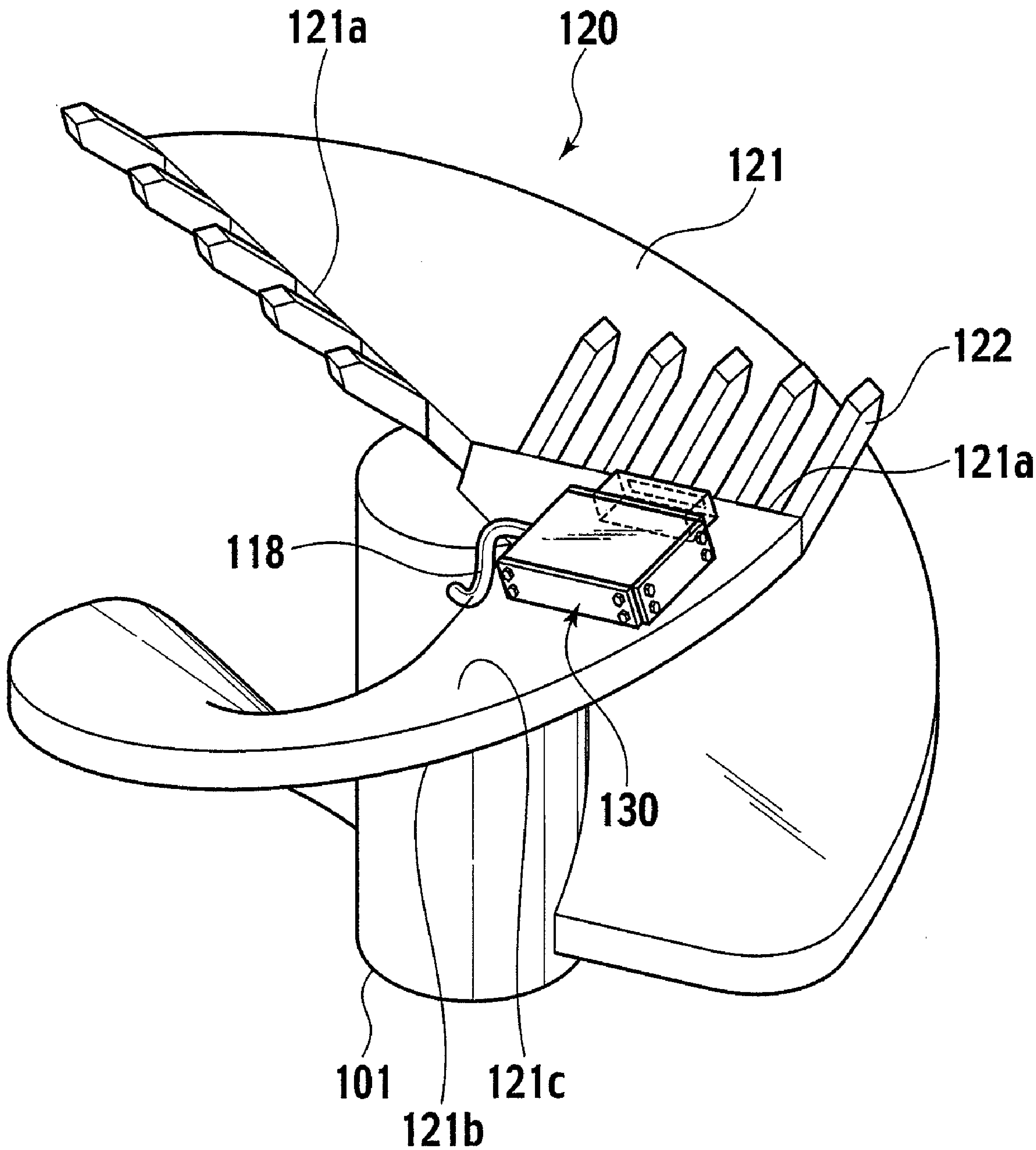
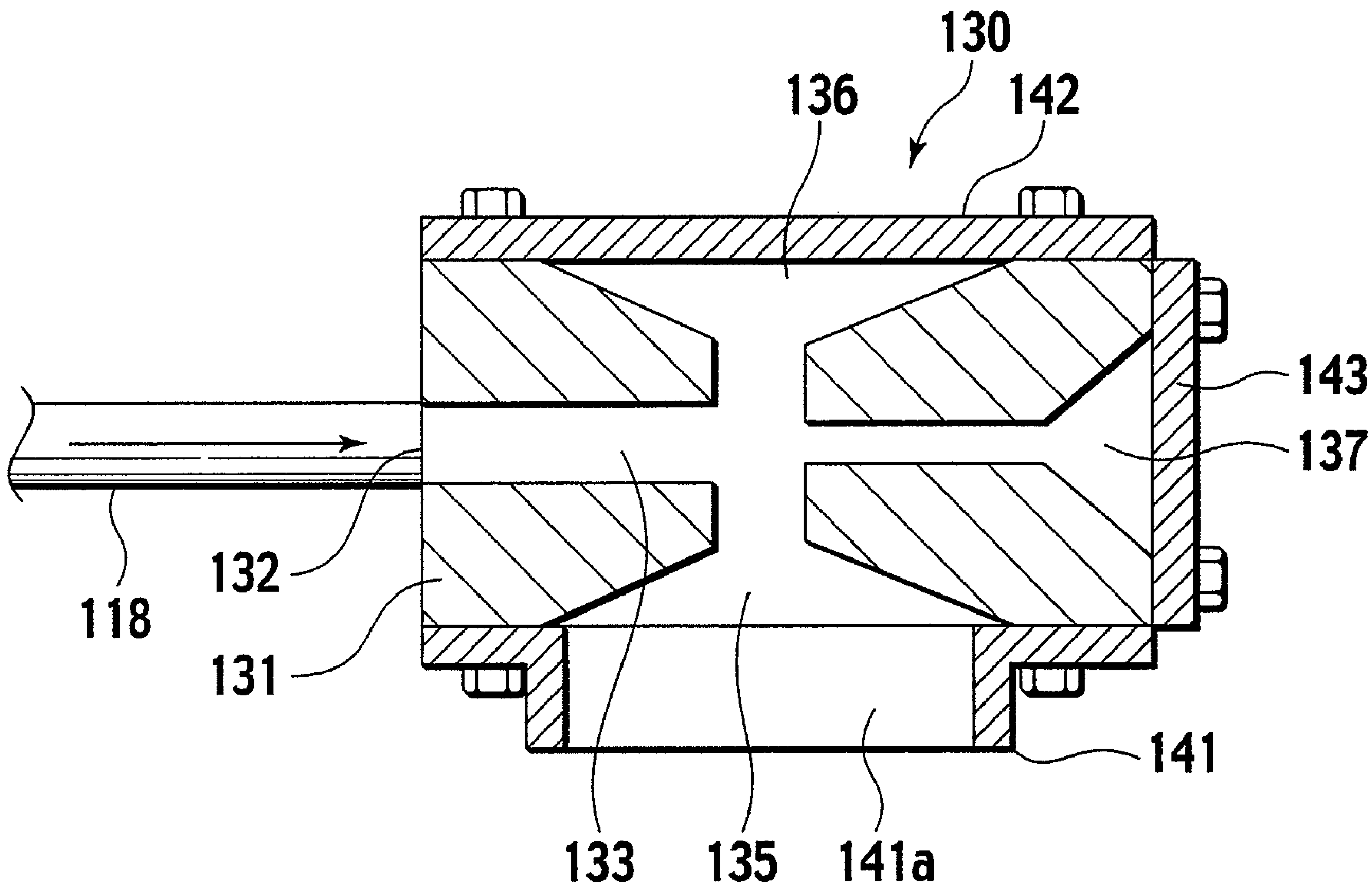
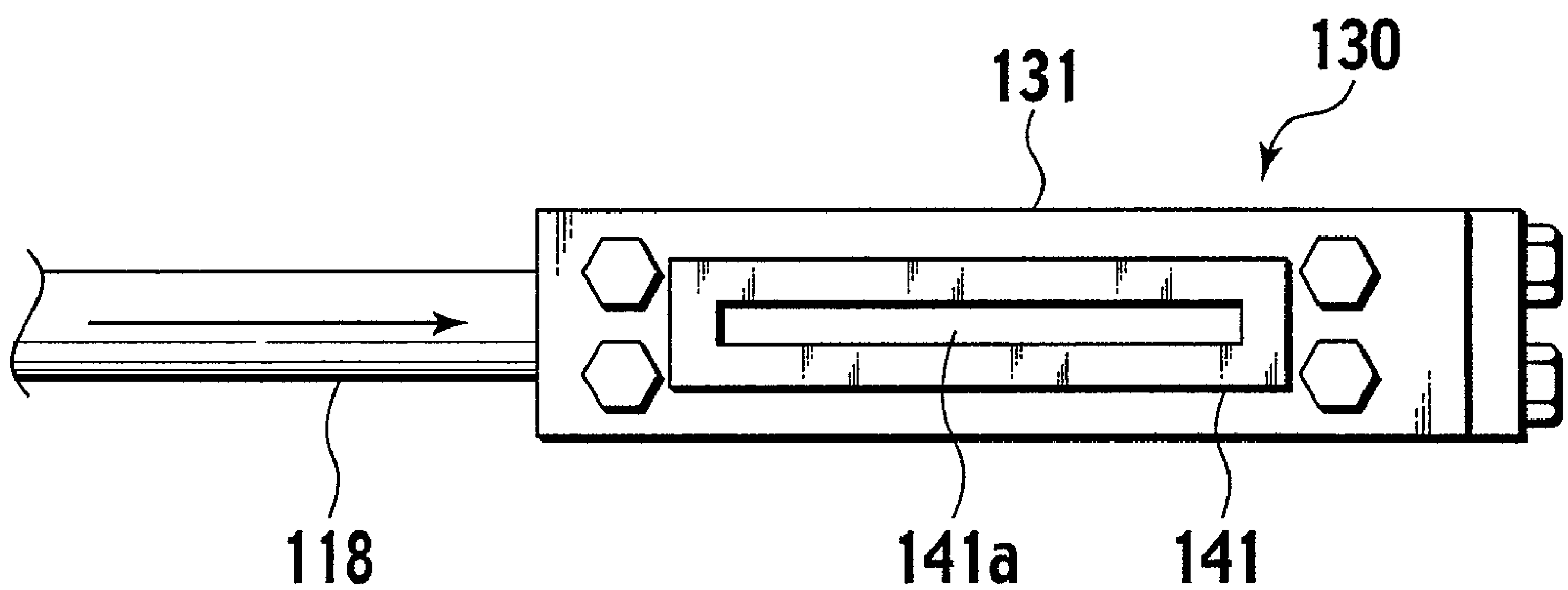


FIG. 8A



130
136
142
143
137
118
132
131
141
133
135
141a

FIG. 8B



131
130
118
141a
141

FIG. 9

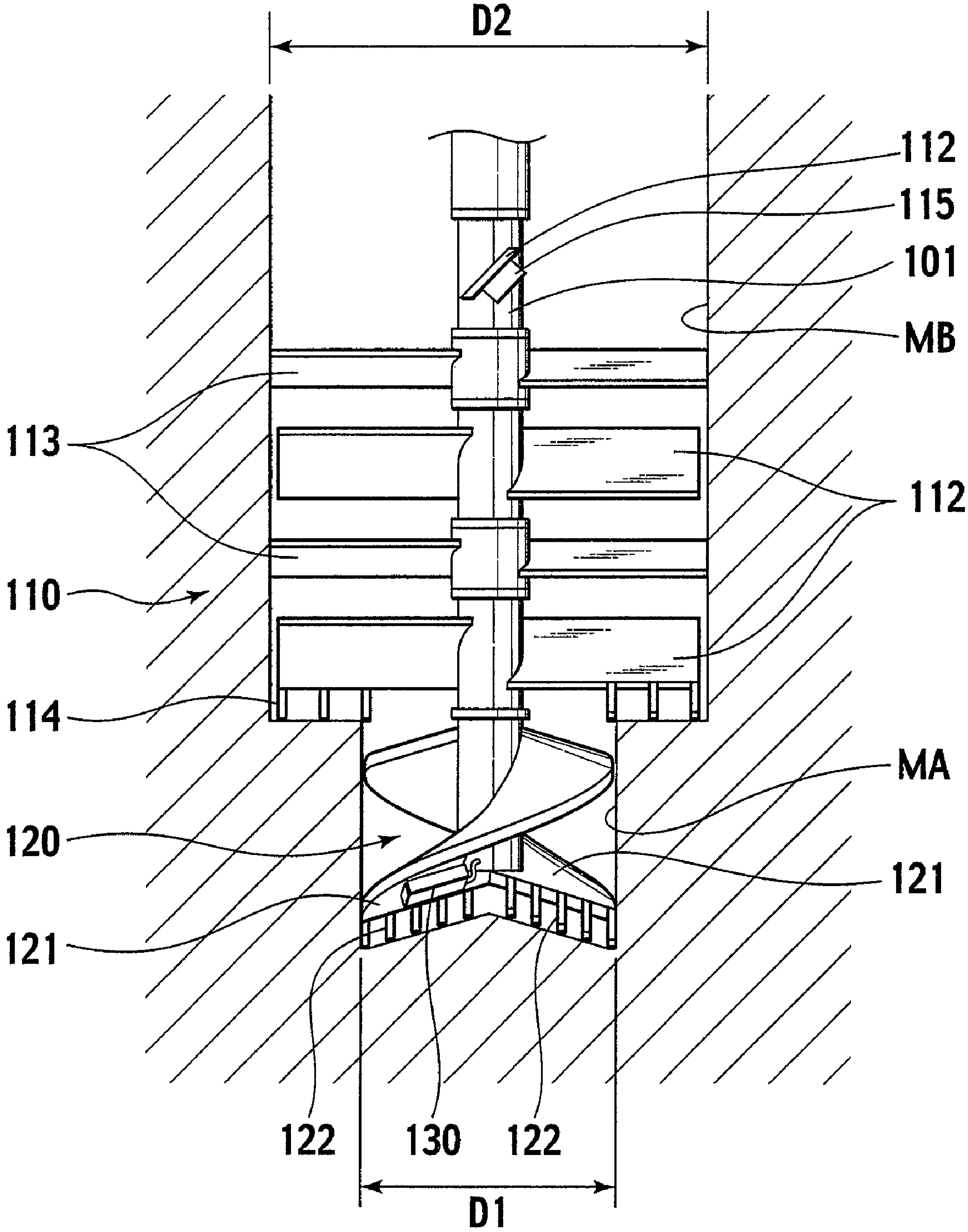


FIG. 10

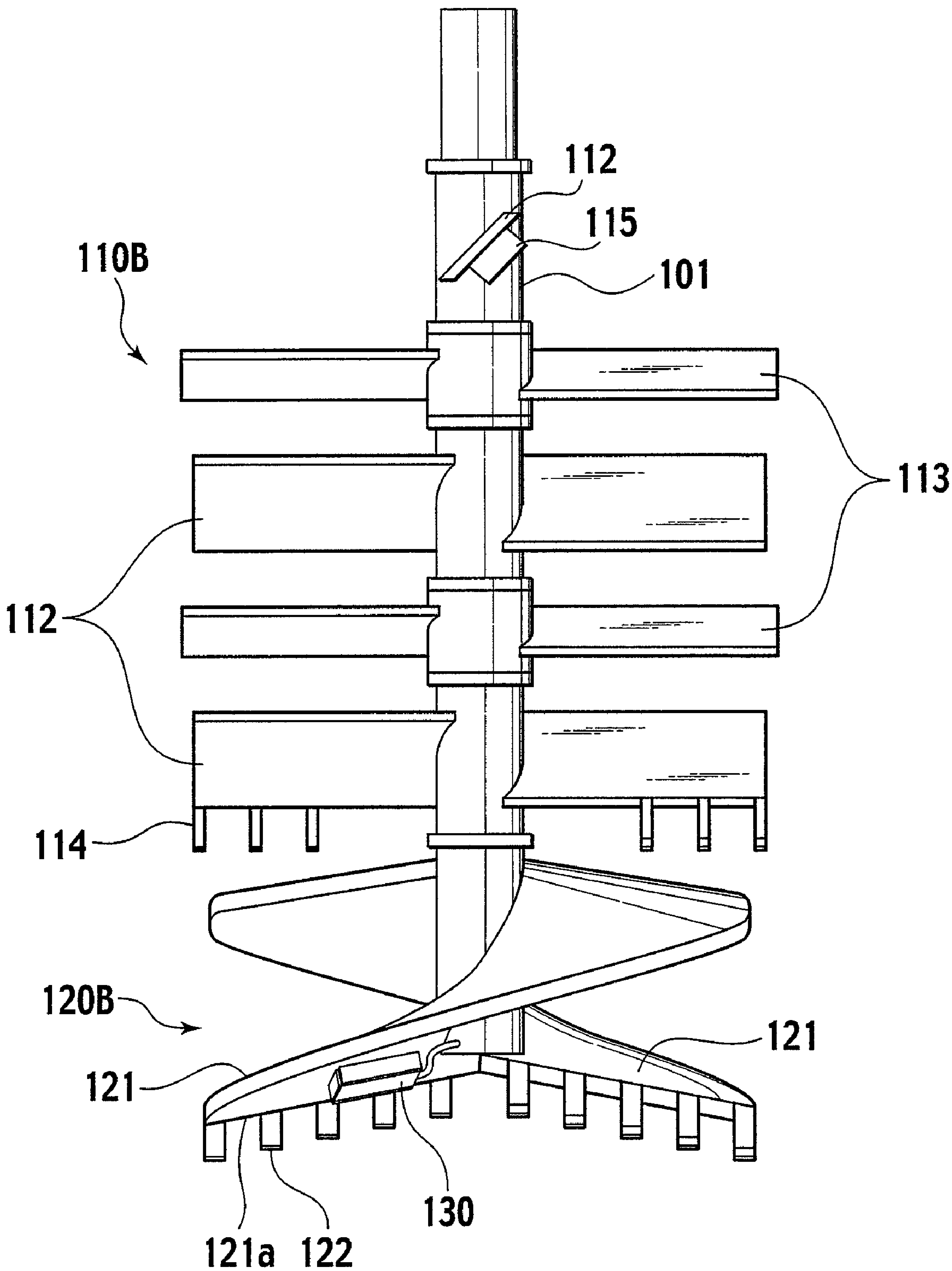


FIG. 11

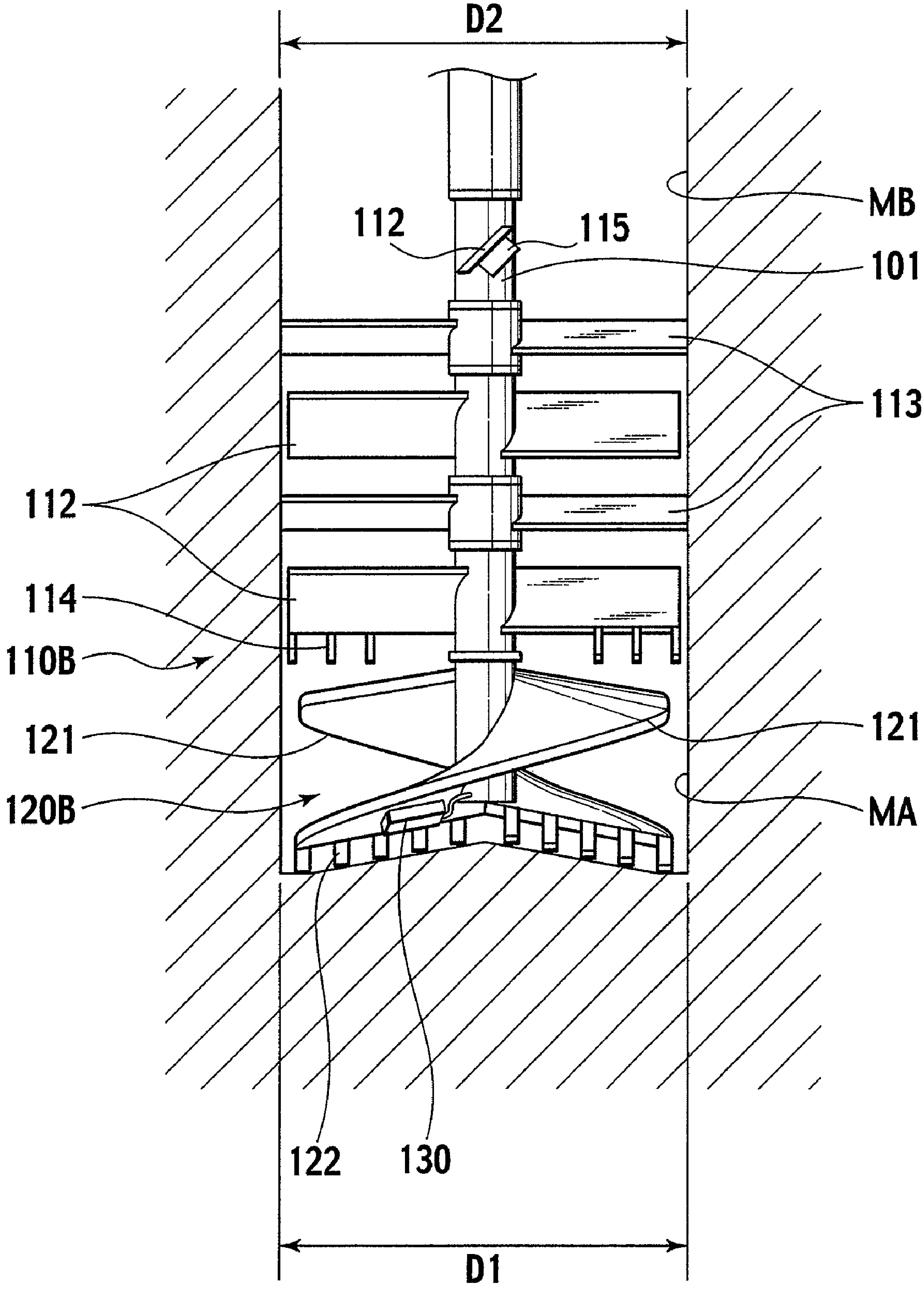


FIG. 12

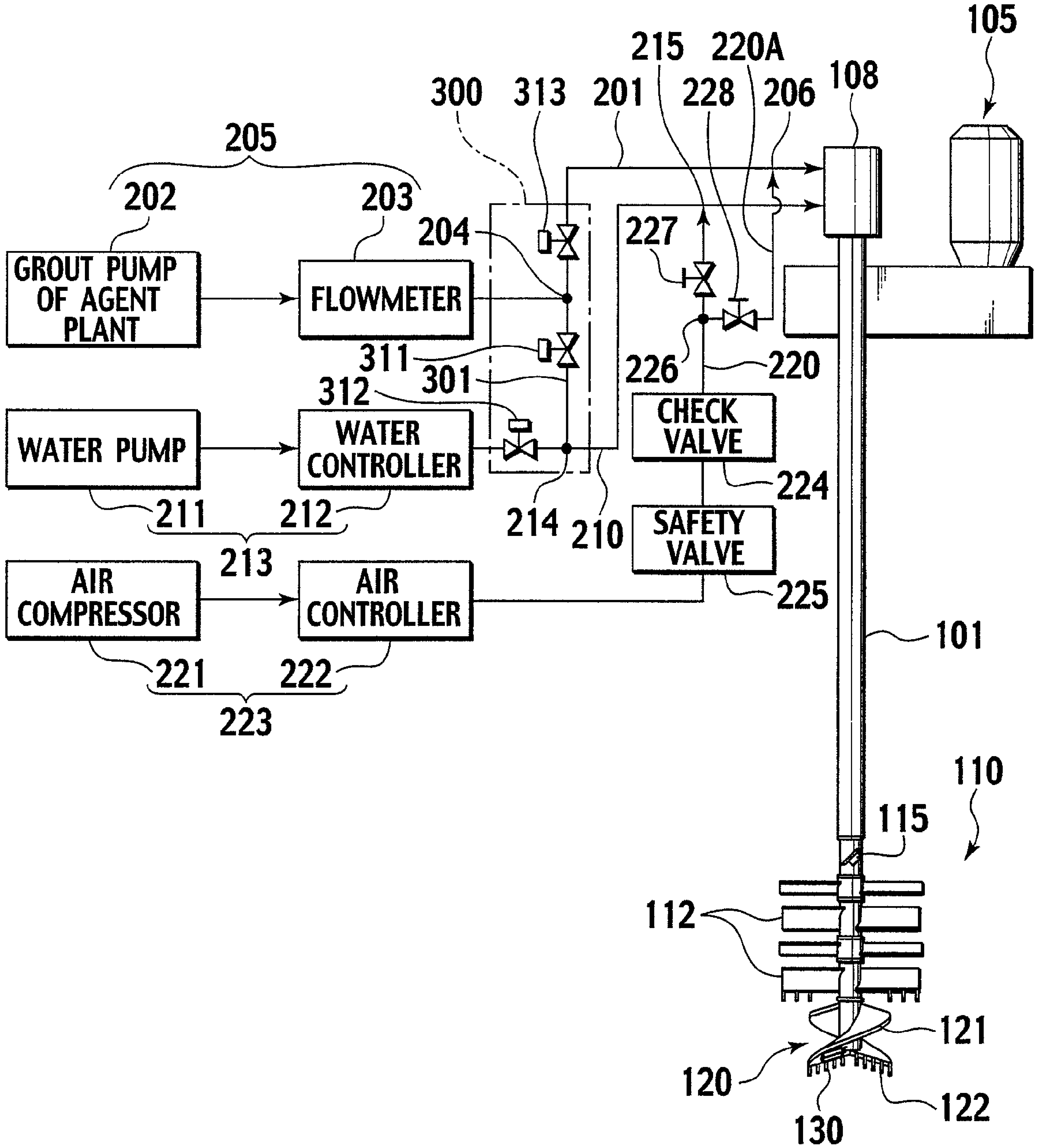
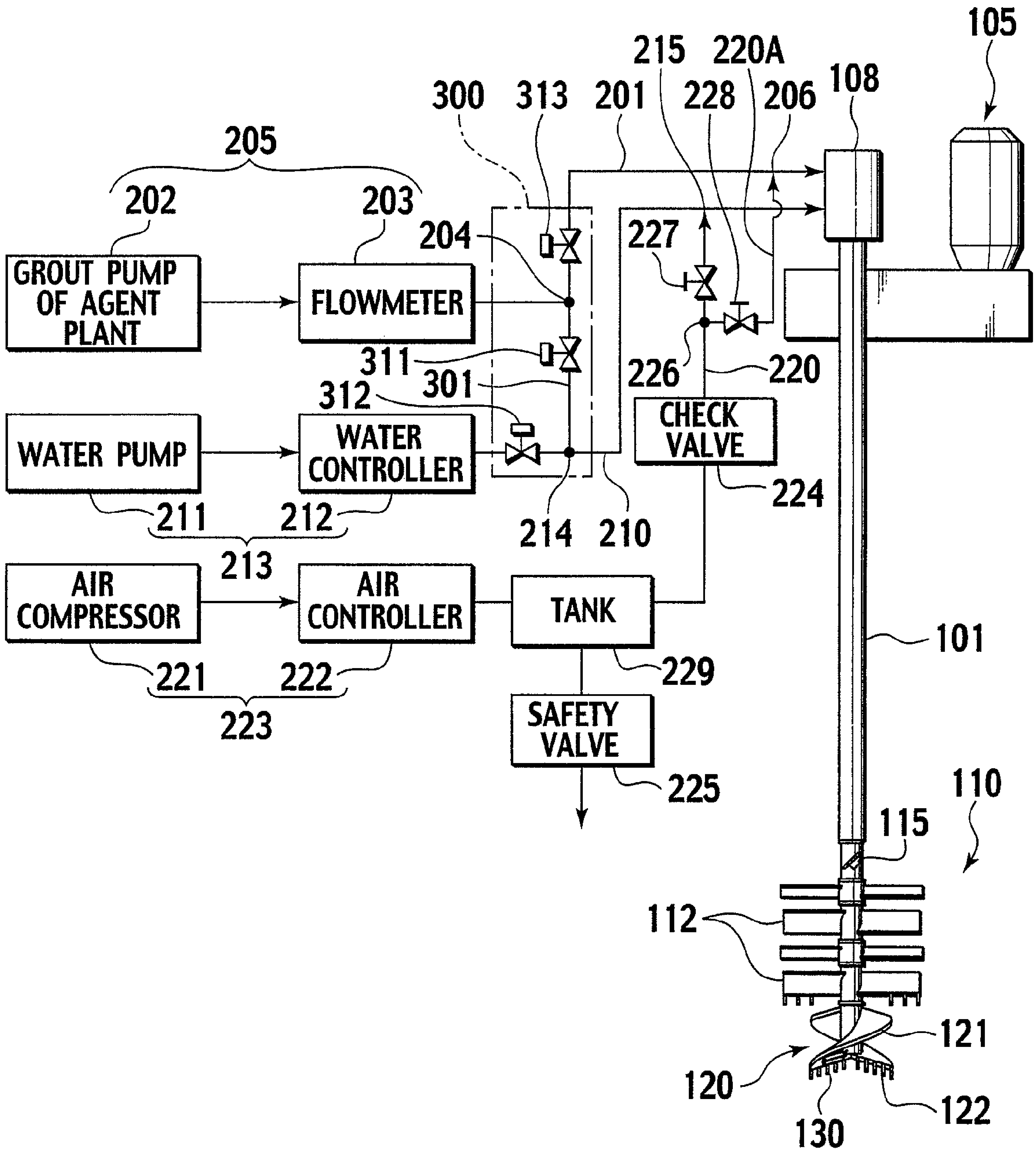

105
215
220A
108
300
313
201
228
206
205
202
203
204
227
GROUT PUMP OF AGENT PLANT
FLOWMETER
311
301
226
220
312
CHECK VALVE
WATER PUMP
WATER CONTROLLER
224
211
212
214
210
SAFETY VALVE
213
AIR COMPRESSOR
AIR CONTROLLER
225
101
221
222
223
110
115
112
121
120
122
130

FIG. 13


GROUT PUMP OF AGENT PLANT
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AIR COMPRESSOR
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CHECK VALVE
105
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220A
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228
206
205
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227
311
301
312
226
220
224
211
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122
130

DRILLING HEAD, METHOD OF SOIL IMPROVEMENT WORK AND APPARATUS THEREOF

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a drilling head attached to a leading end of a rotary shaft, capable of reducing drilling resistance and easily drilling the ground to put the rotary shaft into the ground. The present invention also relates to a method of and an apparatus for soil improvement work with the use of the drilling head.

2. Description of the Related Art

A method of soil improvement work generally includes feeding a fluid from a fluid source on the ground to a leading end of a rotary shaft to be penetrated into the ground and ejecting the fluid from an ejection mouth toward the ground to be drilled, the ejection mouth being arranged on a mixing blade or a drilling head attached to the leading end of the rotary shaft.

Related arts are disclosed in, for example, Japanese Unexamined Patent Application Publications No. 2002-13131 and No. 2002-74049. According to the related arts, supply sources installed on the ground feed compressed air and a liquid through separate paths formed inside a rotary shaft to a leading end of the rotary shaft and eject the liquid with the compressed air from a mixing ejector arranged on a mixing blade toward drilled soil.

FIG. **1** shows an apparatus for soil improvement work disclosed in the Japanese Unexamined Patent Application Publication No. 2002-13131. In FIG. **1**, a rotary shaft **501** is penetrated into the ground. The rotary shaft **501** incorporates an air path **502** for passing compressed air and a liquid path **503** for passing a liquid material. The air path **502** has a top inlet **502***a* that is connected to piping **504***a* extending from an air source **504** for supplying compressed air. The liquid path **503** has a top inlet **503***a* that is connected to piping **505***a* extending from a liquid source **505** for supplying the liquid material.

The air path **502** has a bottom outlet **502***b*, and the liquid path **503** has a bottom outlet **503***b*. The outlets **502***b* and **503***b* are connected to a mixing ejector **507** arranged on a mixing blade **506** attached to a lower end of the rotary shaft **501**. The mixing ejector **507** mixes the compressed air supplied through the air path **502** with the liquid material supplied through the liquid path **503** and ejects the mixture.

FIG. **2** shows an example of a drilling head according to a related art used for an apparatus for soil improvement work. This drilling head is disclosed in Japanese Unexamined Patent Application Publication No. 2005-133367. In FIG. **2**, the drilling head **520** is attached to a leading end of a rotary shaft **501**. The drilling head **520** has a convex shape with a downward apex being on an axis of rotation. Along each ridge slope of the drilling head **520**, drill bits **522** are arranged.

FIG. **3** shows another example of a drilling head disclosed in Japanese Unexamined Patent Application Publication No. 2006-37708. In FIG. **3**, the drilling head **620** is attached to a leading end of a rotary shaft **501**. The drilling head **620** has two spiral blades **621**. Bottom edges of the spiral blades **621** are in the same virtual plane and each of the bottom edges is provided with drill bits **622** whose tips are substantially at the same level.

SUMMARY OF THE INVENTION

The related art shown in FIG. **1** supplies compressed air through the air path **502**, mixes the compressed air with a liquid material in the mixing ejector **507**, and ejects the mixture toward drilled soil. This technique can effectively reduce friction and improve a mixing effect with a small amount of water. Arranging the paths **502** and **503** for different fluids in the rotary shaft **501** and mixing the fluids with each other in the mixing ejector **507** just before ejecting the fluids toward drilled soil need a number of paths (**502**, **503**) to be installed inside the rotary shaft **501**, thereby complicating swivel joints and piping inside the rotary shaft **501** and increasing facility cost.

Existing apparatuses for improving the ground usually have only one or two fluid paths inside a rotary shaft, and therefore, the existing apparatuses are unable to adopt the techniques disclosed in the Japanese Unexamined Patent Application Publications No. 2002-13131 and No. 2002-74049 because the disclosed techniques compel the existing apparatuses to achieve large design changes and bear high cost.

In consideration of the problems of the related arts, the present invention provides a method of and an apparatus for soil improvement work, capable of suppressing a cost increase, reducing a drilling resistance when driving a rotary shaft into the ground, and improving a construction efficiency.

According to the related art shown in FIG. **2**, the drilling head **520** has a convex sectional shape with a downward protruding center. This shape may provide a good cutting performance but it easily causes an axial displacement when it hits a local hard obstacle. In addition, thrust acting on the drilling head **520** pushes soil under the drilling head **520** sideward, and therefore, the drilling head **520** hardly bites the ground.

According to the related art shown in FIG. **3**, the drilling head **620** has the drill bits **622** that are horizontally arranged to bore the ground. This arrangement may be resistive to an axial displacement when it hits a local hard obstacle. The arrangement, however, involves a large drilling resistance because the center and periphery of the drilling head **620** simultaneously cut the ground, thereby deteriorating a drilling efficiency.

In consideration of these problems, the present invention provides a drilling head capable of preventing an axial displacement and efficiently drilling the ground. The present invention also provides an apparatus for soil improvement work employing such a drilling head.

A first aspect of the present invention provides a drilling head attached to a lower end of a rotary shaft to be penetrated into the ground. The drilling head includes a plurality of spiral blades arranged at regular intervals around an axis of rotation of the rotary shaft and drill bits attached to a lower edge of each of the spiral blades. When the rotary shaft is rotated, the lower edges of the spiral blades define an envelope with a central part of the envelope rising in an upward direction from an outer circumferential part of the envelope.

A second aspect of the present invention provides a method of soil improvement work. The method includes drilling the ground with a drilling head arranged at a lower end of a rotary shaft, to sink the rotary shaft into the ground and mixing one of pressurized water and a stabilizer with compressed air on the ground, to prepare a fluid mixture. When driving the rotary shaft into the ground, the method feeds the fluid mixture through a first feed line arranged along the rotary shaft into the drilling head, ejects the fluid mixture from the drilling head toward drilled soil, and sends the rotary shaft up to a predetermined depth.

A third aspect of the present invention provides an apparatus for soil improvement work. The apparatus includes a rotary shaft vertically supported and to be penetrated into the ground, a drilling head arranged at a leading end of the rotary shaft, a lifting driver configured to rotate and move up/down the rotary shaft, a first conduit arranged along the rotary shaft, an ejector arranged on the drilling head and connected to a first end of the first conduit, a water feeder and an air feeder arranged on the ground, water piping configured to feed pressurized water from the water feeder into a second end of the first conduit, a joint arranged at a location that is upstream from and in the vicinity of a connection between the water piping and the first conduit, air piping configured to feed compressed air from the air feeder into the joint, a check valve arranged in the air piping, to prevent the fluid from reversely flowing from the joint, and a safety valve arranged in the air piping and upstream from the check valve, to release pressure if the pressure exceeds a predetermined level.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side view showing an apparatus for soil improvement work according to a related art;

FIG. **2** is a side view showing an example of a drilling head according to another related art;

FIG. **3** is a side view showing another example of a drilling head according to still another related art;

FIG. **4** is a side view generally showing an apparatus for soil improvement work according to an embodiment of the present invention;

FIG. **5** is a view partly showing the apparatus of FIG. **4**;

FIG. **6** is a side view showing a drilling-mixing unit arranged at a leading end of a rotary shaft of the apparatus of FIG. **4**;

FIG. **7** is an upside-down perspective view showing a drilling head of the drilling-mixing unit of FIG. **6**;

FIG. **8**A is a sectional view showing an ejector arranged on a back face of a spiral blade of the drilling head of FIG. **7**;

FIG. **8**B is a side view showing the ejector of FIG. **8**A;

FIG. **9** is a sectional view showing the ground drilled with the drilling-mixing unit of FIG. **6**;

FIG. **10** is a side view partly showing a drilling-mixing unit of an apparatus for soil improvement work according to another embodiment of the present invention;

FIG. **11** is a sectional view showing the ground drilled with the apparatus of FIG. **10**;

FIG. **12** is a view showing an apparatus for soil improvement work according to still another embodiment of the present invention; and

FIG. **13** is a view showing an apparatus for soil improvement work according to still another embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be explained with reference to the accompanying drawings.

FIG. **4** is a side view generally showing an apparatus for soil improvement work according to an embodiment of the present invention. The apparatus includes a rotary shaft **101**. The rotary shaft **101** is movable up and down and is supported substantially plumb with a guide **103***a* of a leader **103** installed on a base machine **102**. The rotary shaft **101** is moved up and down by a lifting driver **104** that is suspended with wires. The lifting driver **104** includes a motor **105** as a rotational driver. In the apparatus for soil improvement work, the lifting driver **104** moves the rotary shaft **101** up and down and the motor **105** turns the rotary shaft **101**, so that a drilling-mixing unit **110** attached to the rotary shaft **101** may drill the ground. After drilling the ground, the apparatus ejects a stabilizer into drilled soil and mixes the stabilizer with the soil, thereby improving the soil. The leader **103** has a steady mechanism **150** arranged at a lower part of the leader **103**, to guide the rotary shaft **101** when the rotary shaft **101** is driven going into the ground.

FIG. **5** is a view partly showing the apparatus of FIG. **4**. The rotary shaft **101** incorporates a first conduit (not shown) that defines a first feed line for passing a friction reducing fluid that is a mixture of pressurized water and compressed air. The rotary shaft **101** also incorporates a second conduit (not shown) that defines a second feed line for passing a stabilizer. The first and second feed lines are different from each other.

The stabilizer is, for example, cement slurry that is supplied from a stabilizer feeder **205** installed on the ground. The stabilizer feeder **205** includes an agent plant grout pump **202** and a flowmeter **203**. The grout pump **202** sends a suspension of stabilizer, which is passed through the flowmeter **203**, stabilizer piping **201**, and a swivel joint **108** into a top inlet of the second conduit arranged inside the rotary shaft **101**. The stabilizer piping **201** also defines the second feed line.

On the ground, a water feeder **213** and an air feeder **223** are arranged. The water feeder **213** includes a water pump **211** for pressurizing water and a water controller **212** for controlling the pressure and flow rate of pressurized water. The pressurized water is passed through water piping **210** and the swivel joint **108** into a top inlet of the first conduit arranged inside the rotary shaft **101**. The water piping **210** also defines the first feed line for passing a friction reducing fluid.

Just before a connection between the water piping **210** and the swivel joint **108**, there is a joint **215** to which a front end of air piping **220** is connected. The air piping **220** extends from the air feeder **223**.

The air feeder **223** includes an air compressor **221** and an air controller **222** for controlling the pressure and flow rate of compressed air. The compressed air is passed through the air piping **220** into the joint **215** where the compressed air is mixed with the pressurized water supplied through the water piping **210** of the first feed line. Generally, a pressure of the pressurized water is higher than a pressure of the compressed air, and therefore, air bubbles are mixed and compressed into fine air bubbles when the compressed air is mixed with the pressurized water. The fine air bubbles are dispersed through the pressurized water, and the mixture passes the first feed line up to an ejector **130** attached to the drilling-mixing unit **110**.

There is a possibility that the pressure of the water piping **210** greatly differs from the pressure of the air piping **220**. To cope with such a situation, a check valve **224** is arranged in the air piping **220**, to prevent a fluid from reversely flowing from the joint **215** into the air piping **220**. In addition, a safety valve **225** is arranged also in the air piping **220** upstream from the check valve **224**, to release pressure if the pressure exceeds a set level.

Between the stabilizer piping **201** and the water piping **210**, a selector **300** is arranged to guide, if required, the stabilizer from the stabilizer feeder **205** to the first conduit that is usually used to pass pressurized water. In the selector **300**, connection piping **301** connects a branch point **204** of the stabilizer piping **201** to a branch point **214** of the water piping **210**. Passage of the connection piping **301** is controllable by opening and closing a first valve **311**. When the first valve **311** is opened, a second valve **312** is closed to prevent a fluid from reversely flowing from the branch point **214** of the connection piping **301** toward the upstream side of the water piping **210**. A third valve **313** is arranged in the stabilizer piping **201** downstream from the branch point **204** of the connection piping **301**. The third valve **313** is interlocked with the first valve **311** and is oppositely opened/closed from the first valve **311**. The first to third valves **311** to **313** are solenoid valves that are controlled by a controller (not shown) in an interlocked manner.

Drilling-Mixing Unit

FIG. **6** is a side view showing the drilling-mixing unit **110** arranged at a leading end of the rotary shaft **101** of the apparatus of FIG. **4**. In FIG. **6**, the drilling-mixing unit **110** includes a drilling head **120** attached to a leading end of the rotary shaft **101**. Above the drilling head **120**, mixing blades **112** and corotational plates **113** are alternately arranged in plural stages in a vertical direction. According to the embodiment of FIG. **6**, the rotational radius of the drilling head **120** is smaller than that of the mixing blades **112**.

Each mixing blade **112** has a bar shape that linearly extends from the rotary shaft **101** in a radial direction and inclines relative to the axis of the rotary shaft **101**. The lowermost mixing blades **112** have drill bits **114** along lower edges thereof, to realize a drilling function in addition to the mixing function. A back face of the uppermost mixing blade **112** is provided with a discharger **115** to discharge the stabilizer fed through the second conduit arranged inside the rotary shaft **101**. The discharging of stabilizer from the discharger **115** is mainly carried out when the rotary shaft **101** is lifted from a hole drilled in the ground by the rotary shaft **101**.

The drilling head **120** includes two spiral blades **121** each having a bottom edge **121**a provided with drill bits **122**. The spiral blades **121** are 180° -symmetrical with respect to the rotary shaft **101**. Each spiral blade **121** is twisted within an angular range of 180° , i.e., each spiral blade **121** extends for a half pitch.

The bottom edges of the spiral blades **121** define an envelope, which is preferably a cone with its center being higher in a z-direction than its periphery. In FIG. **6**, the bottom edge **121***a* of each spiral blade **121** forms a linear slope that rises from a peripheral end thereof toward an inner end thereof. When the drilling head **120** is turned, the lower edges **121***a* of the two spiral blades **121** form a conical envelope with its center upwardly protruding and its periphery being lower than the center. The bottom edge **121***a* of the spiral blade **121** has a vertical face that extends substantially in the z-direction. To the vertical face, the drill bits **122** are attached. An angle α formed between the two bottom edges **121***a* is set to be in the range of 45° to 180°.

When the drilling head **120** is turned and thrust, the drilling head **120** bites into the ground and upwardly pushes soil toward the rotary shaft **101**, to stabilize the center of rotation and efficiently discharge the soil in an upward direction.

FIG. **7** shows the ejector **130** attached to a back face **121***c* (opposite to a front face **121***b* for upwardly scooping soil) of one of the spiral blades **121**. The ejector **130** is used to eject a friction reducing fluid. FIGS. **8**A and **8**B show the details of the ejector **130**. In FIGS. **8**A and **8**B, the ejector **130** includes a body **131** that is a rectangular block and covers **141**, **142**, and **143** fixed to the body **131** with bolts.

The body **131** has an inlet **132** on an end face thereof, to receive a friction reducing fluid. The inlet **132** is connected to a branch pass **133** communicating with ejection mouths **135**, **136**, and **137** that are open to the remaining end faces of the body **131**, respectively. When the ejector **130** is attached to the back face **121***c* of the spiral blade **121**, the ejection mouth **135** faces a rotational direction of the spiral blades **121**, the ejection mouth **136** faces opposite to the rotational direction of the spiral glace **121**, and the ejection mouth **137** faces an outward radial direction of the spiral blade **121**. The inlet **132** of the body **131** is connected to a pipe **118** at a front end of the first conduit arranged inside the rotary shaft **101**.

The ejection mouths **135**, **136**, and **137** have removable covers **141**, **142**, and **143**, respectively. Among the covers, only the cover **141** is provided with an opening **141***a* to open the ejection mouth **135** toward the outside. The other covers **142** and **143** close the ejection mouths **136** and **137**, respectively. When the open cover **141** is attached, the corresponding ejection mouth **135** is opened. When the closed covers **142** and **143** are attached, the corresponding ejection mouths **136** and **137** are closed. Accordingly, by replacing the covers **141** to **143** with one another, any one of the ejection mouths **135**, **136**, and **137** can selectively be opened.

Method of Soil Improvement Work

A method of soil improvement work according to an embodiment of the present invention using the above-mentioned apparatus for soil improvement work and drilling head will be explained.

1. The lifting driver **104** and motor **105** are driven to turn the rotary shaft **101** and descend the drilling head **120** toward the ground. The drilling head **120** at the leading end of the rotary shaft **101** drills the ground to send the rotary shaft **101** into the ground.

2. During the drilling operation, the water feeder **213** feeds pressurized water and the air feeder **223** feeds compressed air. The pressurized water and compressed air are mixed with each other at the joint **215**, to form a fluid mixture with air bubbles dispersed through the pressurized water.

3. The fluid mixture serving as a friction reducing fluid is passed through the first feed line including the swivel joint **108** and the first conduit in the rotary shaft **101** up to the drilling head **120**.

4. The fluid mixture fed to the drilling head **120** is ejected from one of the ejection mouths **135**, **136**, and **137** of the ejector **130** toward drilled soil. In the example of FIG. **8**A, the ejection mouth **135** is open, and therefore, the fluid mixture is ejected through the cover **141** and opening **141***a* of the ejection mouth **135** in a forward direction of a rotational direction of the spiral blades **121**.

5. When the rotary shaft **101** reaches a predetermined depth, the grout pump **202** is driven to feed a stabilizer. The stabilizer is passed through the stabilizer piping **201** and second conduit in the rotary shaft **101** and is discharged from the discharger **115** attached to the mixing blade **112**. At the same time, the rotary shaft **101** is lifted up so that the stabilizer is mixed with site soil to form an improved pillar or pile.

These steps carried out with the apparatus for soil improvement work can efficiently improve soil at the site.

Drilling Resistance of Drilling Head

Jetting a mixture of pressurized water and compressed air from one of the ejection mouths **135** to **137** attached to the drilling head **120** toward drilled soil efficiently reduces friction or resistance between the drilling head **120** and the soil and improves a drilling efficiency. This results in minimizing an axial displacement θ of the rotary shaft **101** shown in FIG. **4** due to uneven drilling resistance.

The bottom edges **121***a* of the spiral blades **121** of the drilling head **120** define a conical envelope having an upwardly protruding central part and a lower circumferential part. As a result, the lower circumference of the envelope first bites the ground. Even if the ground locally contains hard obstacles, the drill bits **122** on the peripheral side of the bottom edges **121***a* of the spiral blades **121** first drill the ground, so that the rotary shaft **101** may be stable irrespective of the obstacles.

The apparatus according to the embodiment, therefore, can minimize an axial displacement θ of the rotary shaft **101** due to irregular drilling resistance and correctly perform drilling. The recessed central part and protruding peripheral part of the drilling head **120** cause a drilling strength difference between the center and the periphery of the drilling head **120**. As a result, strong peripheral drilling force pushes soil toward the center of the drilling head **120**, to improve a drilling efficiency and prevent an axial deviation. The two spiral blades **121** can efficiently convey the soil. The apparatus of the embodiment needs a small thrusting force to produce a sufficient drilling force to drill the ground.

Mixing Compressed Air with Pressurized Water

Pressurized water from the water feeder **213** and compressed air from the air feeder **223** are mixed with each other into a fluid mixture containing dispersed very small air bubbles. The fluid mixture is passed through the first conduit in the rotary shaft **101** up to the drilling head **120**. This configuration minimizes the number of conduits installed in the rotary shaft **101**, thereby saving cost.

Only by forming the joint **215** in the water piping **210** and connecting the air piping **220** to the joint **215**, compressed air can be dispersed into pressurized water to form a fluid mixture. With this simple structure, the fluid mixture can be introduced into a single conduit arranged inside the rotary shaft **101**.

The check vale **224** and safety valve **225** are arranged in the air piping **220** before the joint **215**. Even if the pressure of the water piping **210** suddenly increases, the check valve **224** can surely prevent pressurized water from reversely flowing toward the air feeder **223**. Even if the pressure of the air piping **220** suddenly increases, the safety valve **225** can prevent the pressure from exceeding a predetermined level. This configuration secures the safety of the air feeder **223**.

Ejecting Fluid Mixture from Ejector

The back face of the spiral blade **121** of the drilling head **120** is provided with the ejector **130**, which is provided with the ejection mouths **135** to **137** to determine a fluid ejection direction. This configuration enables a mixture of pressurized water and compressed air to be ejected in a required direction. The mixture of water and air is prepared before it enters the ejector **130**. Namely, the ejector **130** is not required to mix water and air with each other. Accordingly, the ejector **130** having the ejection mouths **135** to **137** can freely be laid out with the ejection mouths **135** to **137** being oriented in proper directions.

Among the ejection mouths **135** to **137**, one is opened and the remaining ones are closed. The opened one is provided with an open cover, and the closed ones are provided with closed covers, so that a fluid mixture is ejected in a direction selected from a forward direction of a rotational direction of the spiral blades **121**, a direction opposite to the forward direction, and an outward radial direction of the rotational direction of the spiral blades **121**.

When drilling the ground mainly made of low viscosity material such as sand, a mixture of pressurized water and compressed air is ejected in a forward direction of a rotational direction of the spiral blades **121**, to reduce drilling resistance in front of the spiral blades **121**. If the ground to drill has a large viscosity, the water-air mixture is ejected in a direction opposite to the forward direction, to reduce resistance against sediments moving along the back faces of the spiral blades **121**, thereby reducing drilling resistance. When drilling the ground for making a joint pile, the water-air mixture is ejected in an outward radial direction of the spiral blades **121**, to reduce rotational resistance along the peripheries of the spiral blades **121**.

Modifications

FIG. **9** shows that a radius of rotation of the drilling head **120** is smaller than that of the mixing blade **112**. As a result, the diameter D**1** of a bottom MA of a drilled hole is smaller than the diameter D**2** of an improved body (pile) forming hole MB. Accordingly, a portion corresponding to the height of the drilling head **120** will be out of specification for a required pile having a predetermined diameter and a predetermined depth (height). To form the required pile, a hole to be dug for the pile must be deeper by the height of the drilling head **120** than the required height of the pile. FIGS. **10** and **11** show a drilling-mixing unit **110**B according to a modification of the present invention. A radius of rotation of a drilling head **120**B of the unit **110**B is substantially equal to that of a mixing blade **112**. As a result, the diameter D**1** of a bottom MA of a drilled hole is substantially equal to the diameter D**2** of an improved body (pile) forming hole MB. In this case, the drilled hole will entirely have an effective diameter for the pile to be formed.

As explained above, the discharger **115** is arranged on the uppermost mixing blade **112**, to discharge a stabilizer to be mixed with drilled soil at the site. In addition to this, the selector **300** is arranged so that the stabilizer may be passed through the water piping **210** and the first conduit arranged inside the rotary shaft **101** to the ejector **130**, which ejects the stabilizer. This configuration can supply the stabilizer into site soil at the level of the drilling head **120**.

The stabilizer may be discharged from both the ejector **130** on the drilling head **120** and the discharger **115** on the mixing blade **112** at an optional ratio that may freely be changed in the range of 10:0 to 0:10. To achieve this, the second valve **312** is closed and the first and third valves **311** and **313** are opened at a proper opening ratio. A portion of the stabilizer is passed through the stabilizer piping **201** and second conduit to the discharger **115** on the mixing blade **112**, and the remaining portion of the stabilizer is passed through the water piping **210** and first conduit to the ejector **130** on the drilling head **120**. Thereafter, the stabilizer is discharged from both the discharger **115** and ejector **130** into drilled soil.

If the ground to drill is soft, the rotary shaft **101** is penetrated into the ground by switching the supply of water and the supply of a stabilizer from one to another, so that the ejector **130** on the drilling head **120** may alternately eject pressurized water and the stabilizer therefrom. This technique can mix the stabilizer with drilled soil while the rotary shaft **101** is being submerged into the ground.

If the ground to drill is hard, the rotary shaft **101** is penetrated into the ground with the ejector **130** on the drilling head **120** ejecting pressurized water therefrom. After the rotary shaft **101** is put into a predetermined depth, the rotary shaft **101** is lifted up with the discharger **115** on the mixing blade **112** discharging a stabilizer and also the ejector **130** on the drilling head **120** ejecting the stabilizer, so that the stabilizer is mixed with site soil.

The selector **300** is easily realizable by providing the stabilizer piping **201** and water piping **210** with the connection piping **301** and three valves **311** to **313**.

First Modification

FIG. **12** shows an apparatus for soil improvement work according to a first modification of the present invention.

According to the apparatus of the first modification, stabilizer piping **201** has an air inlet **206**. The air inlet **206** is connected to a front end of air piping **220**A that is branched from a branch point **226**. The branch point **226** is formed in air piping **220** downstream from a check valve **224**. This arrangement can introduce compressed air into a stabilizer passed through the stabilizer piping **201**. Two valves **227** and **228** are provided for the air piping **220** downstream from the branch point **226**, to guide compressed air of the air piping **220** into one of the air inlet **206** of the stabilizer piping **201** and a joint **215** of water piping **210**.

When drilling the ground, the valve **227** is opened and the valve **228** is closed to mix compressed air with pressurized water to form a fluid mixture, which is fed to a drilling head **120**, thereby achieving the effect of the above-mentioned embodiment. In a mixing operation, the valve **227** is closed and the valve **228** is opened, to mix compressed air with the stabilizer passed through the stabilizer piping **201**, so that the air-mixed stabilizer is discharged into and mixed with drilled soil. By mixing compressed air with a stabilizer, the fluidity of the stabilizer can be adjusted to improve the mixing ability of the stabilizer.

For this, the air piping **220**A is branched from the air piping **220** on the downstream side of the check valve **224**. The valves **227** and **228** are used to determine a connection object of compressed air. This configuration can effectively use compressed air both for drilling and mixing without increasing a facility cost.

Second Modification

FIG. **13** shows an apparatus for soil improvement work according to a second modification of the present invention.

The second modification is basically the same as the first modification of FIG. **12** except that a tank **229** is arranged in piping between an air controller **222** and a check valve **224** and the tank **229** is connected to a safety valve **225**.

Even if water or stabilizer (cement slurry) reversely flows through the check valve **224** toward the air controller **222**, the water or stabilizer can be discharged to the outside through the tank **229** and safety valve **225**, thereby surely preventing the water or stabilizer from entering the air controller **222**.

This application claims benefit of priority under 35 U.S.C. 119 to Japanese Patent Applications No. 2006-244141 filed on Sep. 8, 2006 and No. 2006-244145 filed on Sep. 8, 2006, the entire contents of which are incorporated herein by reference. Although the present invention has been described above by reference to certain embodiments of the present invention, the present invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art in light of the teachings. The scope of the present invention is defined with reference to the appended claims.

What is claimed is:

1. A drilling head attached to a lower end of a rotary shaft to be penetrated into the ground, comprising:

a plurality of spiral blades arranged at regular intervals around an axis of rotation of the rotary shaft; and

drill bits attached to a lower edge of each of the spiral blades,

wherein the lower edges of the spiral blades define an envelope with a central part thereof rising in an upward direction from an outer circumferential part thereof as the rotary shaft is rotated,

wherein at least one of the spiral blades is provided with an ejector arranged on a back face of the spiral blade and is configured to eject a resistance reducing fluid that is supplied from a source installed on the ground toward the ground to drill, and

wherein the ejector comprises:

a first ejection mouth configured to eject the fluid in a forward direction of a rotational direction of the spiral blades;

a second ejection mouth configured to eject the fluid in a reverse direction of the rotational direction of the spiral blades; and

a third ejection mouth configured to eject the fluid in an outward radial direction of the rotational direction of the spiral blades, wherein

one of the first, the second, and the third ejection mouths is selectively opened.

2. An apparatus for soil improvement work, comprising:

a rotary shaft vertically supported and to be penetrated into the ground;

a drilling head arranged at a leading end of the rotary shaft;

a lifting driver configured to rotate and move up/down the rotary shaft;

a first conduit arranged along the rotary shaft;

an ejector arranged on the drilling head and connected to a first end of the first conduit;

a water feeder and an air feeder installed on the ground;

water piping configured to feed pressurized water from the water feeder into a second end of the first conduit;

a joint arranged at a location that is upstream from and in the vicinity of a connection between the water piping and the first conduit;

air piping configured to feed compressed air from the air feeder into the joint;

a check valve arranged in the air piping, configured to prevent the pressurized water from reversely flowing from the joint;

a safety valve arranged in the air piping and upstream from the check valve, configured to release pressure if the pressure exceeds a predetermined level;

a mixing blade arranged at a leading end of the rotary shaft above the drilling head;

a second conduit separately arranged from the first conduit along the rotary shaft;

a discharger configured to discharge a stabilizer at a height where the mixing blade is turned, the stabilizer being fed through the second conduit;

a stabilizer feeder installed on the ground, configured to pressurize and feed the stabilizer;

stabilizer piping configured to guide the stabilizer from the stabilizer feeder into an inlet of the second conduit; and

a selector having a plurality of valves configured to selectively guide the stabilizer from the stabilizer feeder into one of the first conduit and the second conduit.

3. The apparatus of claim **2**, wherein the selector comprises:

connection piping configured to connect the stabilizer piping to the water piping;

a first valve configured to open/close the connection piping;

a second valve configured to be closed to prevent the pressurized water from reversely flowing through the water piping in an upstream direction from a connection between the connection piping and the water piping when the first valve is opened; and

a third valve arranged in the stabilizer piping downstream from a connection between the connection piping and the stabilizer piping, to be oppositely opened/closed when the first valve is opened/closed.

4. The apparatus of claim **2**, further comprising:

an air inlet formed in the stabilizer piping; and

air piping configured to guide the compressed air from the air feeder into the air inlet of the stabilizer piping, so that the compressed air is mixed with the stabilizer fed through the stabilizer piping.

5. The apparatus of claim **4**, further comprising:

a branch point formed in the air piping downstream from the check valve, configured to branch the air piping; and

a switching valve configured to selectively guide the compressed air from the air piping into one of the joint of the water piping and the air inlet of the stabilizer piping.

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